First High Field Magnet Cross-Section Design

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Abstract
This note describes the parameters of coil cross-section approved for the first HFM model. Defined more precisely cable parameters were used. Possible changing of insulation scheme was taken into account in re-optimized for this purpose cross-section.

INTRODUCTION

Decision to use HGQ curing fixture at the HFM coil curing stage was used as a starting point to define inner radii of two coil layers. That fixture has inner radius of 52.59mm. Taking into account 1.016mm retainer thickness, 14.52mm insulated cable width and 0.28mm of interlayer insulation one can get inner radii of 22.25mm and 37.05mm for the first and second layers. Number of cables in blocks and block alignments was optimized by ROXIE package [1] to get minimal harmonics content inside 10mm-bore radius. Several cross-sections with different geometrical parameters have been considered. The cross-section with the best radial cable positioning and high enough pole width was taken as a base for the end parts design, mechanical and 3D magnetic calculations. This magnetic design had been reported at PAC99 in New York.

During coils winding for the first mechanical model it was found that S2 glass tape currently used for the cable insulation is not strong enough. It was damaged in several places created turn-to-turn and turn-to-ground shorts. That gave a reason to reconsider used cable insulation procedure. One of possible ways is to use ceramic tape impregnated with ceramic matrix and prebaked before wrapping around the cable. As tests carried out shown, insulation became much stronger and there was no serious insulation damage observed during winding. But drawback of such procedure is increasing of insulation thickness up to 0.25mm (it corresponds to 50% overlap under 25Mpa of pressure) comparing with the butt wrapped 0.125mm thick tape. According to these new results, several attempts were made to get optimized cross-section with increased insulation thickness.

CABLE PARAMETERS

In Table 1 there are base cable parameters measured more precisely, used during cross-section optimization. As a cable insulation was used ceramic tape of 0.125mm thick.

Cable height (bare) , mm	14.232
Cable inner width (bare), mm	1.6870
Cable outer width (bare), mm	1.9130
Number of strands	28
Strand diameter (mm)	1.012
Cabling angle (degree)	14.5
Cu/SC ratio	0.85
Critical current density at 12 T & 4.2 K (A/mm^2)	1886

Table 1: Cable parameters

BASE CROSS-SECTION DESIGN

Layers radial distribution has been described above. Iron yoke was simulated by an area started at 60mm radius from the center of coil with constant magnetic permeability equals 1000. Figure 1 shows field quality diagram and figure 2 shows cross-section layout with wedges and pole spacers after optimization.
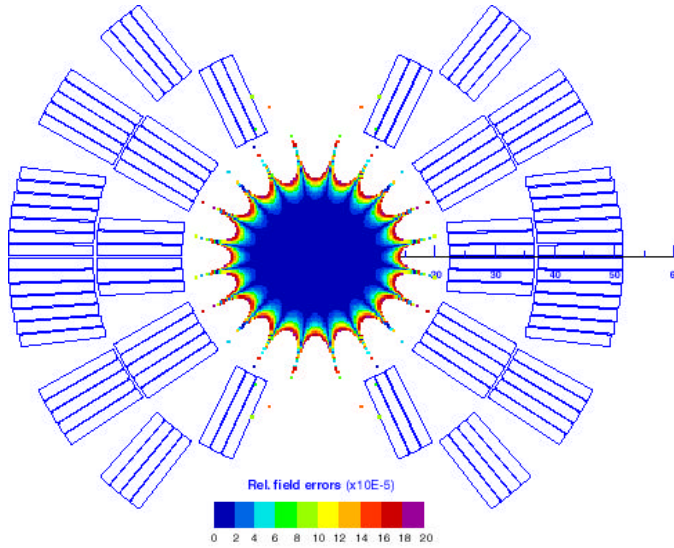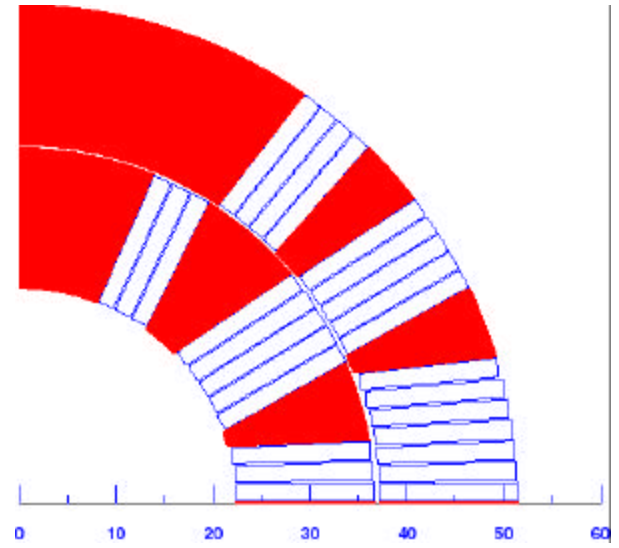

Fig 1: Field quality diagram

Fig 2: Wedges and pole spacers layout

Block #	Number of turns	Positioning angle φ, deg.	Inclination angle α, deg.
1	7	0.193	0.000
2	5	24.342	29.007
3	4	44.393	48.584
4	3	0.322	0.000
5	5	19.320	29.549
6	3	53.920	63.451

Table 2: Design Parameters

Parameter	Unit	
Number of turns		54
Cu area	mm^2	1154.3
Sc area	mm^2	1358.1
Total coil area	mm^2	2512.4
NI/Bo	A/T	79786
Bss	T	12.28
Iss	A	18139
Stored energy @11T	kJ/m	251.86
Inductance	mH/m	1.91
Pole width	mm	16.36
Harmonics @ 1 cm		
b3	10^-4	-5E-05
b5	10^-4	0.00016
b7	10^-4	-0.0068
b9	10^-4	-0.0713
b11	10^-4	0.10323
b13	10^-4	0.00311

Table 3: Design Characteristics

In Table 2 are given geometrical design parameters: positioning and inclination angles for lowest cable in each block. In Table 3 are presented the most important parameters for the base cross-section.

CHANGES IN CROSS-SECTION

According to the possible insulation scheme it was made several steps to re-optimize the base cross-section for thicker cable insulation. It was considered two cases, when insulation width is 0.23mm (50% overlap, 50Mpa) and 0.25mm (50% overlap, 25MPa). Since radial insulation increases (it was assumed equal to azimuthal insulation), it leads to changing radial position of coil layers: to fit curing fixture the radii of the first/second layers must be 21.84/ 36.85mm for 0.23mm and 21.75/36.875mm[*] for 0.25mm insulation. The bare cable dimensions and iron yoke ID were taken from the base cross-section without changes.

During optimization it was found a necessity to remove two turns from outer coil layer for 0.23mm insulation and three turns for 0.25mm insulation to get reliable cable arrangements and wedges size.

Two cross-section cases for 0.23mm and one for 0.25mm insulation with different number of cables in outer layer blocks were generated. Figure 3-8 shows field quality

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[*] For 0.25mm insulation are used updated retainer thickness 0.508mm and curing fixture inner radius 52.123mm

diagrams and wedges layout. The design characteristics for all the cases are summarized in Table4.
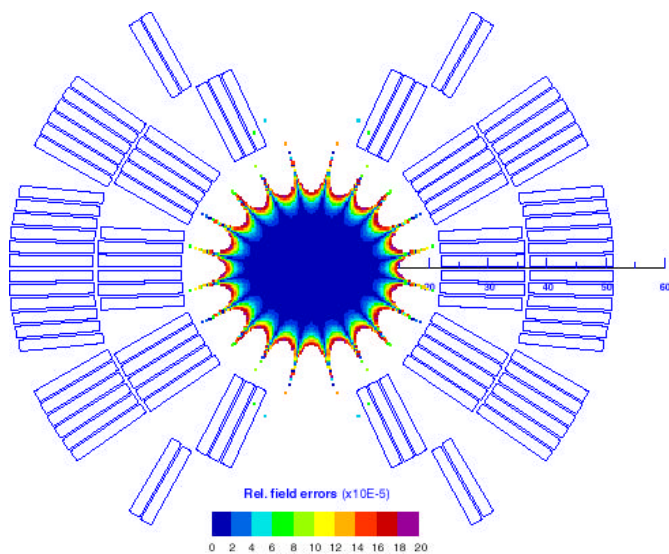

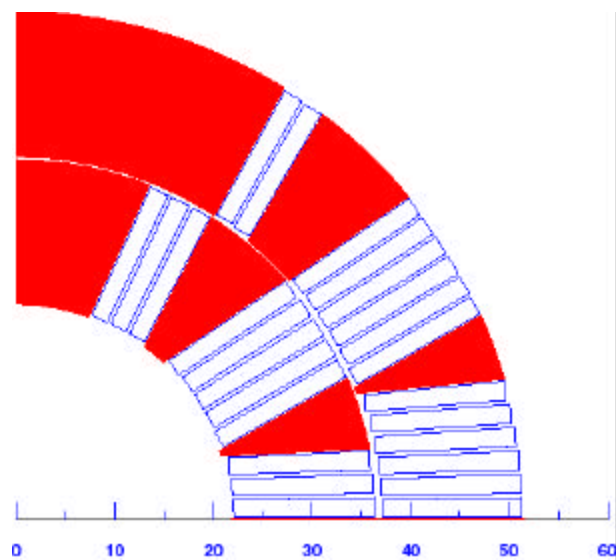Fig 3: Field quality diagram for case #1

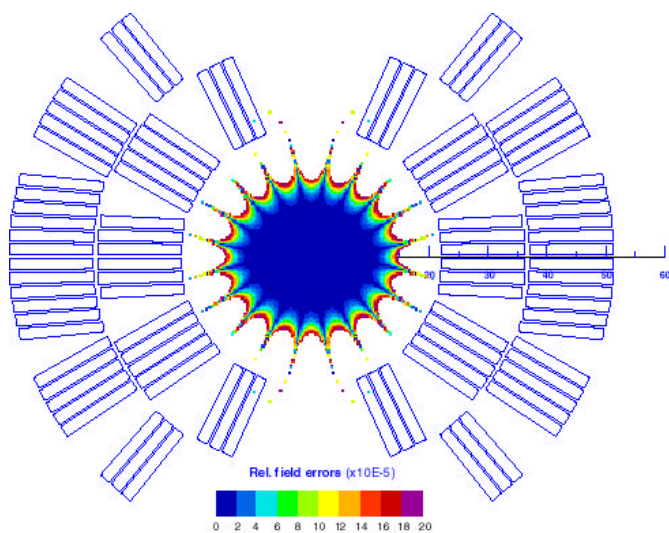Fig 4: Wedges and pole spacers layout for case #1

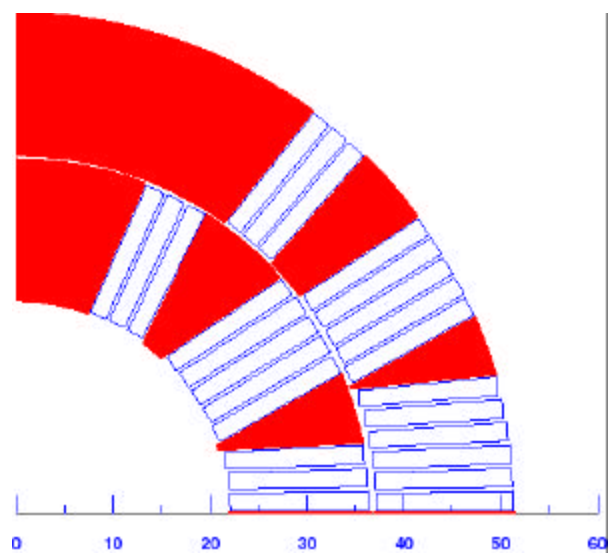Fig 5: Field quality diagram for case #2

Fig 6: Wedges and pole spacers layout for case #2
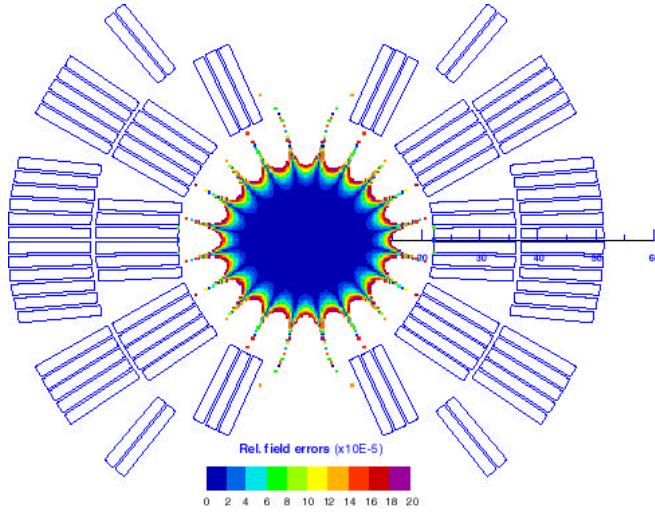
Fig 7: Field quality diagram for case #3

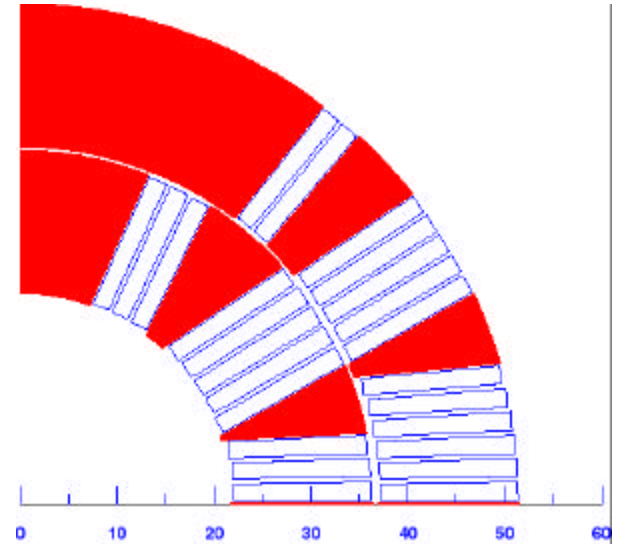Fig 8: Wedges and pole spacers layout for case #3

Parameter	Unit	#1	#2	#3
Cable insulation thickness	mm	0.23	0.23	0.25
Number of turns		50	50	48
Cu area	mm^2	1069	1069	1026
Sc area	mm^2	1257	1257	1207
Total coil area	mm^2	2326	2326	2233
NI/Bo	A/T	78780	78675	78179
Bss	T	12.11	12.12	12.02
Iss	A	19087	19070	19574
Stored energy @11T	kJ/m	244	244	241
Inductance	mH/m	1.62	1.63	1.50
Pole width	mm	15.35	15.39	15.09
Harmonics @ 1 cm				
b3	10^-4	-0.00014	-0.00005	-0.00007
b5	10^-4	-0.00037	0.00068	0.00001
b7	10^-4	-0.00076	-0.00083	0.00016
b9	10^-4	-0.0892	-0.0903	-0.0906
b11	10^-4	0.0987	0.0982	0.0988
b13	10^-4	-0.0006	-0.0006	-0.0017

Table 4: Design characteristics for 1-3 cases

CONCLUSION

As a result of optimization it was obtained the base coil cross-section that has following features:

- All conductor blocks have a radial alignment that will gives an advantage during coil winding;
- The pole key width is large enough to bend the relevant cable around;
- Magnetic field quality at 10mm radius aperture meet our preliminary criteria (SSC specifications);
- All wedges are wide enough and all outer wedges are supported by inner wedges that will provide an additional mechanical stability of coil assembly.

Also, taking into account the results of optimization with wider cable insulation it is possible to conclude that the chosen base cross-section can be adjusted for different insulation thickness without essential deterioration of field quality and transfer function.

REFERENCES

1. S. Russenchuck
   A Computer Program for the Design of Superconducting Accelerator Magnets

   CERN AT/95-39, LHC Note 354, Geneva, Switzerland, 26 Sept. 1995